Brief Communication: Estimates of Some Demographic Parameters in a Neolithic Rock-Cut Chamber (Approximately 2000 BC) Using Iterative Techniques for Aging and Demographic Estimators

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ABSTRACT Two new techniques—one anthropological, which estimates the mean age at death for adult skeletons, the other demographic, which gives main survivorship curve parameters—are used on a sample of skeletons (N ≅ 170) discovered in a Neolithic rock-cut chamber (Loisy-en-Brie, France). The iterative technique for aging used a stochastic sampled ***F*** matrix derived from the trabecular involution of the femoral head observed in the reference collection of Coimbra (Portugal; N = 421). The results, obtained from techniques and data, independent of each other, are strongly consistent. Overall, they give a life expectancy at birth of about 25–28 years and the probability of death at 1 and 5 years, respectively, of about .271–.249 and .429–.380. Am J Phys Anthropol 102:569–575, 1997.

In May 1968, a rock-cut chamber dug into the chalk was discovered in a vineyard in Champagne after the collapse of its vault, at Loisy-en-Brie (place Les gouttes d'or). It is one of more than 150 rock-cut chambers currently known in the region (department of La Marne) (Chertier et al., 1994) since the 1870s. On its floor were found a modest neolithic assemblage (tranchet arrowheads; polished axes in their antler sleeves; beads of chalk, bone, and shell; flat-based coarse pottery) and the remains of about 170 people in an exceptional state of preservation (Chertier et al., 1994). This rock-cut chamber belongs to the so-called Seine-Oise-Marne (SOM) culture. Its C^{14} date is 3690 ± 100 BP (Gif 2169) (i.e., calibrated 2387–1788 BC). The Neolithic population used this burial place with economy. They pushed their dead close together (see Fig. 1). The skeletons exhumed from the rock-cut chamber offered exceptional research conditions. The dead represent a population sample left by Neolithic people themselves, and the corpses were not buried in the earth. They were simply laid down on the floor of the monument, side by side. The bones are in an excellent state of preservation and exempt from any soil penetration. But the frequent comings and goings of Neolithic people in the chamber have disturbed the bones of numerous skeletons. Only a few were still in anatomical juxtaposition when they were found, creating a kind of giant puzzle of mixed skeletal elements.

While aging methods for children's skeletons are reasonably reliable, this is not the case for adults. The methods published in the literature are gravely biased, due to the a priori probability of the age estimates they carry, determined by the age distributions of the anthropological reference collections

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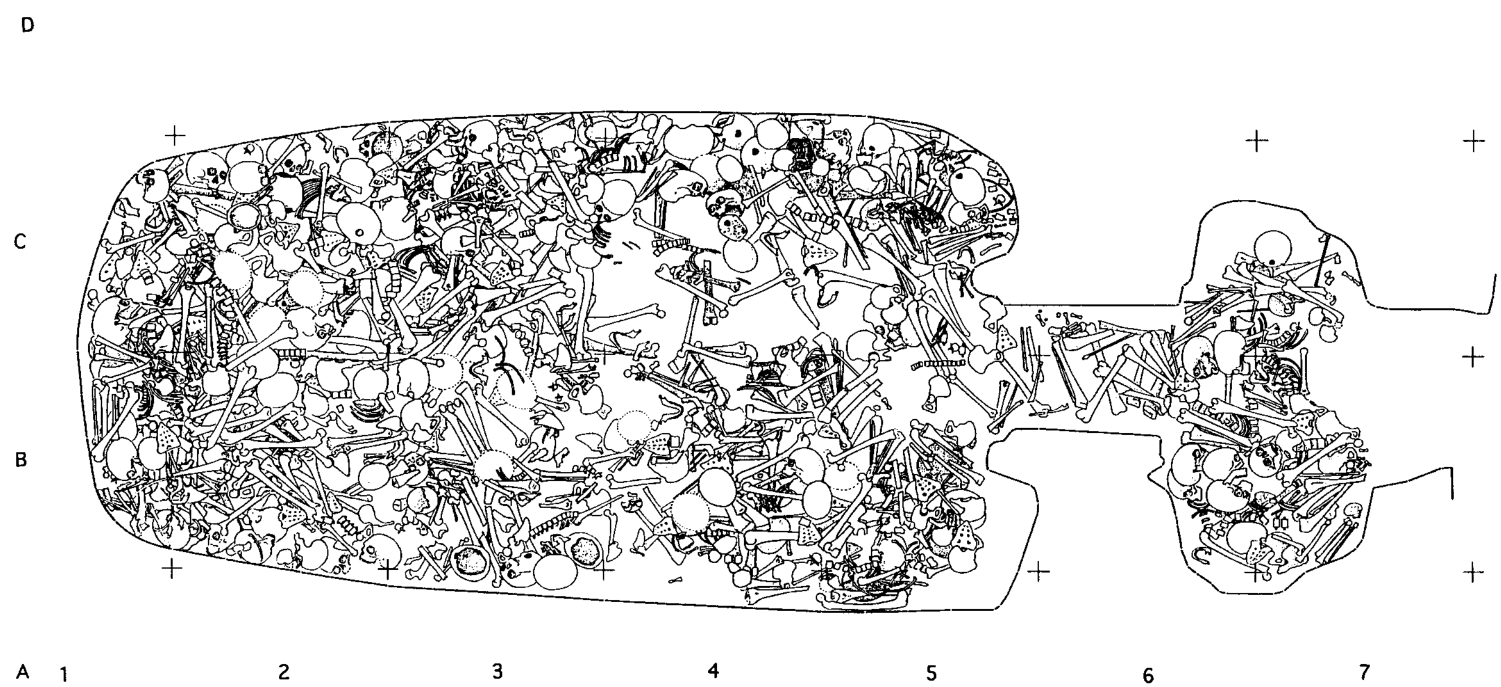

Fig. 1. A view of the rock-cut chamber of Loisy-en-Brie (Marne, France) dated 3,690 ± 100 BP. Some 170 skeletons are scattered on the ground in an exceptional state of preservation.

upon which they are based (Bocquet-Appel and Masset, 1982). Most of the paleodemographic studies, therefore, mainly mirror the age distribution of these reference skeleton collections. This discovery led to a great deal of controversy, which has yet to be resolved (Van Gerven and Armelagos, 1983; Bocquet-Appel and Masset, 1985; Buikstra and Konigsberg, 1985; Jackes, 1985, 1992, 1993; Bocquet-Appel, 1986; Wood et al., 1992).

In fact, it is hardly possible to estimate the age-class distributions for adults. However, it is possible to assess accurately the average of this unknown age distribution (in the range 20–90 years), using a new iterative technique, which is free of the influence of the a priori probability of the reference collections (Bocquet-Appel and Masset, 1996).

Two algorithms can be found in the anthropological literature. One is derived from the iterative proportional fitting procedure (IPFP) (dating back to Deming and Stephan, 1940); the other is an expectancy maximization (EM) algorithm named iterated age-length key (IALK) by Kimura and Chikuni (1987) and Konigsberg and Frankensberg (1992) and improperly called iterative Bayesian (IB) in Bocquet-Appel and Masset (1996). One can demonstrate analytically that both algorithms, although written differently, have the same step two and lead in fact to the same solution. Thus, their results are quite close if not the same (Bocquet-Appel and Masset, 1996). Both the IPFP and the IALK techniques were applied to the adult skeletons of Loisy en Brie. In addition, new paleodemographic estimators were computed from a set of 40 archaic life tables, which directly incorporate the hypothesis, assumed by the anthropologist, for the rate of increase. The age indicator used is trabecular involution in the femoral head (Acsádi and Nemeskéri, 1970; Bergot and Bocquet, 1976) and the reference sample of the University of Coimbra, Portugal (Bocquet et al., 1978).

This paper provides a practical application of the two techniques developed by Bocquet-Appel and Masset (1996) along with some complementary methodological explanations. It also gives estimates for the life expectancy at birth and the probability at death at 1 and 5 years for the neolithic population that inhabited Loisy-en-Brie around 2000 BC.

TABLE 1. Age distribution of the preadults at Loisy-en-Brie

Age (years)	Frequency (counts)
0	4
1–4	15
5–9	15
10–14	7
15–19	9
20–22	6
23+	108
Total	164

AGING

Subadults: Dental eruption of preindustrial populations, degree of synostose of the bones, and their corresponding probabilities in age classes

The subadult age distribution was estimated by the degree of synostosis of the calvarium, ilium, and femur (Olivier, 1973; McKern and Stewart, 1957) along with the stages of dental eruption observed in two samples of preindustrial European children, one including infants and the deciduous dentition (Frison and Planchon, cited in Legoux, 1962), the other including children past infancy and the permanent detentition (Mühlreiter, 1920). The first sample was obtained in 1898–1904 in Paris ($N = 250$) and the second in 1870–1890 in Vienna ($N > 40{,}000$). Age estimates above 14 years were mainly based on the degree of synostosis of the long bones (Olivier, 1973; McKern and Stewart, 1957). Individual bones were grouped in the age classes 15–19 and 20–22 on the basis of their degree of synostosis and corresponding probabilities computed from the McKern and Stewart sample (Bocquet, 1977). At 23 years, the suture of the femoral head is closed in all cases (McKern and Stewart, 1957). The estimate of the number of individuals in an age class, subadults and adults, was based on the presence of the four most robust bones of the sample (mandible, pelvis, sacrum, and femur). The highest number among these four bones observed in an age class was taken as its sample size (Bocquet, 1977). The results are presented in Table 1.

*TABLE 2. Reference sample from the Coimbra collection cross-classified in seven age classes and six stages (**N** matrix) for the femoral head*[1]

	Age classes						
Stage	23–29	30–39	40–49	50–59	60–69	70–79	80–89
1	8	2	0	0	0	0	0
2	19	18	6	2	0	0	0
3	30	43	29	26	9	7	2
4	7	25	27	37	28	28	10
5	1	1	5	13	9	10	10
6	0	0	1	0	1	3	5

[1] Ascádi and Nemeskéri, 1970; Bergot and Bocquet, 1976.
Note that dividing each element by the corresponding column total will produce the **F** matrix (the frequency of the stage given the age). The sum of each column for the **F** matrix will be 1, making the reference sample uniformly distributed on the ages (Bocquet 1977). N = 421.

Adults: Iterative technique to estimate the mean age at death

Bocquet-Appel and Masset (1996) compared the efficacy of the proportional fitting and age-length key algorithms to estimate the unknown age distribution and the aggregate age at death using the distributions of biological indicators in a reference sample of known ages. Both techniques give the same results accurately for the average. From a matrix of observations, $\boldsymbol{N} = (n_{ai})$, $r \times c$, giving the cross-classification of the individuals, both in c age classes and r indicator stages, a reference matrix sample is derived, represented by a stochastic matrix, $\boldsymbol{F} = (f_{ia})$, where f_{ia} represents the observed frequency of the ith stage of an indicator ($i = 1, \ldots, r$) in the ath age class ($a = 1, \ldots, c$). In this matrix the ages are uniformly distributed (column total = 1) (see Table 2). The algorithms eliminate the influence of the age distribution of the reference sample on the estimate for the average age in the target sample. The estimate for the average age, x, is simply the mean of the estimated age distribution obtained via the iterative algorithm, $\{m_a\}$, using the set of the mid-age classes corresponding to the $\boldsymbol{F}$ matrix, $\{x_a\}$: $x = \Sigma\, x_a m_a$ ($a = 1, \ldots, c$). While the estimated age distribution is a poor estimate of the unknown true one, this is not the case with its average, which is quite close to the unknown parameter. To estimate the age-class frequencies and the modal age class, the IALK technique gives better results, although well below the confidence interval at 95% for the true topology.

The decision to estimate only one parameter (the average) from the unknown age-at-death distribution was reached by simulations. Discarding the sampling effect, the issue was the following: given a correlation (r_{ia}), age indicator and a (fixed) confidence interval for the parameter values (the age-class frequencies), what is the number of parameters that can be reasonably estimated (i.e., that will give the true topology of the unknown histogram in 95% of the simulations)? Here the confidence interval, d_{kl}, is the absolute difference between two successive age classes (in % of the target sample). Intuitively, the greater d_{kl} is (the contrast between two contiguous age classes), the greater the number of estimable parameters by an iterative technique should be. The simulation results, using the device described in Bocquet-Appel and Masset (1996) show that a topology at only three age classes required an $r_{ia} \cong 0.95$ and a d_{kl} of about 10%. These simulation results are not very different of those already obtained (Table 1 in Bocquet-Appel and Masset, 1982). Such a correlation level for a pattern of aging has never been found. Given biological variability in general, it is doubtful that such very strong correlation will be found in the future. Another EM algorithm has been proposed, which assumes that there are sampling errors in the reference sample (Hoenig and Heisy, 1987). Again, it was evaluated by simulations. But the simulation results appear to be poorer than those produced by the two algorithms quoted above (see Table 3).

For the adults at Loisy-en-Brie, the age indicator was the degree of trabecular involution in the femoral head classified in terms of six stages (Acsádi and Nemeskéri, 1970;

TABLE 3. Number of successes to estimate the true topology for the bimodal distribution (four age classes) by three iterative algorithms[1]

Correlation age indicator	% of true: Realized histograms HH[1]	KC	BM	Detected mode HH	KC	BM
0.9	34.8	61.2[2]	45.4[2]	66.2	90.8[2]	71.9[2]

[1] BM, Bocquet-Appel and Masset; HH, Hoenig and Heisy; KC, Kimura and Chikuni.
[2] From Table 2 in Bocquet-Appel and Masset (1996).

Bergot and Bocquet, 1976). That indicator does not exhibit significant sexual dimorphism, making it useful for aging a sample of individuals when the sex is unknown. Table 2 shows the sample ***N*** matrix (N = 421), representing the reference collection of Coimbra, from which the ***F*** matrix used for the iterative algorithms derived. At Loisy-en-Brie the distribution among the six stages of the indicator, of the 96 usable femoral head (right) on 108 individuals, was 2.0, 8.0, 31.5, 40.5, 12.0, and 2.0, respectively. This is a mean distribution obtained using five attempts by the same observer, because some inevitable ambiguities appeared during the stage determination due to imprecise morphological definitions and the quality of X-ray pictures. One can expect a better quantification for the behavior of this biological indicator using a scanner (Macchiarelli and Bondioli, 1994). Both the reference and the target sample were tomographed, respectively, with a linear (Bergot and Bocquet, 1976) and a cycloïdal X-ray apparatus to obtain better images (Bocquet, 1977).

The average age obtained for this unknown distribution, in the range 23–90 years, is 52.36 and 52.27 years, using the IALK and IPFP algorithm, respectively, and the corresponding mid-age classes. The difference is negligible, and the average age can be rounded off to 52.3 years. With a correlation coefficient between the biological indicator and the age at death of $r \simeq .65$ (Bergot and Bocquet, 1976) and a sample size for adults in the rock-cut chamber of N $\simeq$ 100, the standard error estimated by simulation is ± 3 years (Bocquet-Appel, 1994). If one takes into account the six immature individuals aged between 20 and 22 years (of mean age 21) and the 12 femurs of adults which were unusable (of mean age 52.3), the mean age for the 114 skeletons aged 20 years and older is ([96 + 12] $\times$ 52.3 years + 6 $\times$ 21 years)/114 = 51.6 years.

DEMOGRAPHIC ESTIMATORS FOR MISSING CHILDREN AND DATA

New demographic estimators were obtained in what was later called the "uniformitarian hypothesis" (Howell, 1979). They were computed using two different kinds of information, which can be obtained independently of each other in a cemetery: the mean age at death for adults ($a_{20\text{-}\omega}$) via the iterative technique, and the juvenility index (JI = D5-14/D20-ω). They are represented by multiple regressions based on 40 archaic life tables (i.e., controlled data), discussed elsewhere (Bocquet and Masset, 1977). Coale and Demeny's West model (1983) is not usable, as the authors have eliminated all historical tables prior to 1870 (Coale and Demeny, 1983). This date is too recent for the study of archaic mortality before Jenner and the introduction of vaccination in public health.

The empirical relationships that have been fitted were expressed through polynomial functions to minimize the mean square error (MSE), as for all published model life tables. Among these functions, one of them was selected using a routine statistical package. The multiple correlations obtained, between the true and estimated values for the demographic parameters of the tables, were high, varying from $R^2 = 0.800$–0.955 ($P < 0.001$). The approach predicted variable = f(predictive) = $Y = f(X)$ is referred to as the inverse calibration in the statistical literature (for a review see Osborne, 1991). But, because of the attraction to the mean, inverse calibration can be biased at the limits of its range. Another approach, classical calibration, solves the equation: predictive variable = f(predicted) = $X = f(Y)$ for the predicted variable. Although it may give a better result for the same linear relationships, it is intractable if the function is a polynomial, like those used in the empirical relationship described by Bocquet-Appel and Masset (1977, 1982, 1996). The choice then was either to use the classical calibration but

with a simple linear function, $X = f(Y)$ (i.e., a relatively large MSE), or the inverse calibration, $Y = f(X)$ but with a polynomial function (i.e., a smaller MSE). Given the R^2 obtained, the bias will be, in any case, smaller than the MSE that would be obtained if the classical calibration were used instead, even at the limits, where the inverse calibration may be biased. The new estimators directly incorporate the rate of increase posited by the anthropologist, given the archaeological information. They give the life expectancy at birth ($\hat{e}_0$) and at 20 years ($\hat{e}_{20}$), and the probability of death at one (${}_1\hat{q}_0$) and at five years (${}_5\hat{q}_0$) (Bocquet-Appel and Masset, 1996).

For the whole SOM population, one can hypothesize a positive rate of increase based upon an increased density of cemeteries observed within the region during the XXth millenium BC (Chertier et al., 1994). Therefore, the demographic parameter values at Loisy-en-Brie were estimated under the three following hypotheses for the rate of increase ρ: 0.000, 0.002, and 0.005, with $\hat{a}_{20\text{-}\omega}$ = 50.6 years and JI = 22/114 = 0.1929. The $\hat{e}_0$ varies, depending on the rate of increase hypothesized, from 25–28.6 years, $\hat{e}_{20}$ from 30.6–32.1 years, ${}_1\hat{q}_0$ from .271 to .249, and ${}_5\hat{q}_0$ from .429 to .380.

An indirect means of judging the value of Loisy-en-Brie as a true demographic sample is to compare the consistency of the demographic results produced by each of the two independent data sets (the subadult distribution relative to the adults and the femoral head distribution for the adults) and techniques (estimators and iterative technique). Under the hypothesis of a stationary population ($\rho = 0$) for the sake of comparison, one finds with the estimator based on the preadults, JI (=0.1929), $\hat{e}_0 = 25.2$ years and on the adults, $\hat{a}_{20\text{-}\omega}$ (50.6 − 20 years already lived) $\hat{e}_{20} = 30.6$ years. The model life tables of Ledermann (1969) give for an input of $e_0 = 25$ years, an output at 20 years of $e_{20} = 32$ years. These are values quite close to that obtained by the iterative technique.

Typically, the mortality of the prehistoric populations is described in the following way: the paleodemographic data suggest a pattern of mortality with low infant mortality, high childhood mortality and a very high rate of aging (Gage et al., 1989). Such a pattern was obtained using anthropological methods based on forensic medicine that have been criticized (Masset, 1972; Bocquet-Appel and Masset, 1982, 1985; Bocquet-Appel, 1986). It is interesting to note that it has occasionally produced similar values for the life expectancy at birth to that obtained above by the iterative technique. But in general such results were obtained by mutual cancellation of errors due to a considerable underestimation of infant and child mortality (before five years) and a strong compensatory overestimation of adult mortality (before 55 years).

It would be quite interesting to settle the demographic results obtained at Loisy-en-Brie, for the recent Neolithic, in light of the wave diffusion model of the Neolithic transition into Europe of Ammerman and Cavalli-Sforza (1984). Did the demographic regime change, at the wave front and after the wave, between the ancient and recent Neolithic? If yes, in which direction? A study of some key archaelogical sites, using iterative techniques and demographic estimators for skeletal populations, should be able to answer these important issues.

CONCLUSIONS

On the whole, the results at Loisy-en-Brie, obtained from techniques (iterative procedures for aging, estimators for missing demographic parameters) and data (juvenility index, age indicator distribution in the neolithic and the $\boldsymbol{F}$ matrix sample) which are independent of each other, are strongly consistent. They give a life expectancy at birth, depending on the rate of increase assumed, of about 25–28 years for that peasant neolithic population.

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